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(12) (19) (CA) **Demande-Application**

(21) (A1) **2,250,623**
(22) 1998/10/16
(43) 1999/04/17

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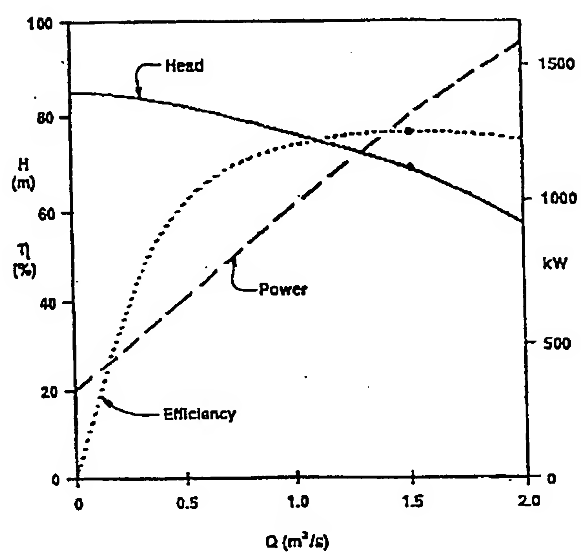
(51) Int.Cl.[6] F04B 49/06, F04B 15/00
(30) 1997/10/17 (08/953,135) US

(54) TECHNIQUE DE COMMANDE DE POMPE A BOUE
(54) TECHNIQUE TO CONTROL SLURRY PUMPS



Representative pump characteristic curves.

(57) Cette invention concerne une méthode de détermination de la pression instantanée développée par une pompe (de la densité correspondante du produit pompé) et de modulation de la dite pression en fonction de la résistance à l'écoulement dans une canalisation, l'objectif étant d'optimiser le rendement de la pompe et de réduire ou d'éliminer les instabilités de fonctionnement et tous ses effets néfastes sur la pompe et la canalisation, notamment la cavitation et l'usure prématurée.

(57) Disclosed is a method of determining the instantaneous pressure produced by the pump (and the internal SG that goes along with that) and how that can be used in relation to the overall total pipeline resistance to control and/or adjust the pump performance to better operate the pump and/or reduce or eliminate the unsuitable unstable operation and all of the adverse cavitation, wear and other effects on the pump and pipeline that go along with unstable operations.

Industrie Canada Industry Canada

TECHNIQUE TO CONTROL SLURRY PUMPS

ABSTRACT

Disclosed is a method of determining the instantaneous pressure produced by the pump (and the internal SG that goes along with that) and how that can be used in relation to the overall total pipeline resistance to control and/or adjust the pump performance to better operate the pump and/or reduce or eliminate the unsuitable unstable operation and all of the adverse cavitation, wear and other effects on the pump and pipeline that go along with unstable operations.

TECHNIQUE TO CONTROL SLURRY PUMPS

BACKGROUND OF THE INVENTION

Figs. 1-8 are performance charts of the prior art pumps.

A common method of transporting solids used in the mining, dredging and other industries is to pump these as a mixture of water and solids inside a pipeline using slurry pumps.

Centrifugal slurry pumps are similar to centrifugal water pumps except that they are modified to better suite and resist the abrasive nature of the slurries they have to pump. These modifications are many, but mostly are more robust construction to accommodate the higher horsepower, fewer vanes to allow the passage of large solids and the construction of the wet end of the pump in thicker, hard metal (or rubber) wear resisting materials.

The slurries that these pumps have transport against generally consists of mixtures of water and various solids of different sizes at different concentrations. Examples of slurries are phosphate matrix, copper ore, taconite ore and crushed rock and sand as is encountered in dredging.

For pipeline transport of a normal crushed rock or other conventional settling slurry to occur as a mixture of water and solids, a certain minimum mean mixture velocity called the deposit velocity, Vsm, must be exceeded.

The deposit velocity varies with the pipe size, particle size, solids SG, particle shape and concentration. A typical slurry is composed of a variety of sizes and shapes of particles, so the deposit velocity is also in practice not one number but a range of velocities over which a bed forms.

The head loss characteristic for most settling slurries at different delivered concentrations is normally taken to be a U-shape as shown in Figure 1 with a minimum head loss value that increases at higher and lower velocities.

For operation with constant speed centrifugal pumps, operation is usually recommended at a velocity at least slightly higher than the larger of the minimum head loss velocity or the deposit velocity shown at constant concentration in Fig. 2, in order to avoid operation where it could be unstable or bed formation occurs.

Calculated Head Loss in Horizontal Conveying

The head loss or pipeline friction along a pipe conveying a settling slurry is conventionally expressed as head in meters (or feet) of carrier liquid per meter (or foot) of pipe, i_m. The corresponding head loss for the carrier liquid alone at the same mixture velocity will be denoted by i_w. The excess head loss resulting from the presence of the solids is then (i_m-i_w). Empirical correlation's usually attempt to predict either (i_m-i_w) or the relative increase in head loss, $(i_m-i_w)/i_w$. Some of these correlations and their applications to slurries containing a wide range of particle sizes are explained by Wasp (Wasp, E.J. et

al. [2], 1977, Solids-liquid flow-slurry pipeline transportation, Trans. Tech Publications.). However, in the writers' experience it is much more reliable to base design on tests carried out on slurry representative of that to be pumped in practice.

A method of scaling up test results consists of distinguishing between different modes of solids transport and assessing the contributions of the different modes to (i_m-i_w).

This approach is derived from Wilson's development (Wilson, K.C., [3], 1992, Slurry Transport Using Centrifugal Pumps. Elsevier Applied Science, London and New York.) of early work on settling slurries by Newitt and Clift (Clift, R., et. Al. [4], 1982, A mechanistically-based method for scaling pipeline tests for settling slurries, Proc. Hydrotransport 8, BHRA Fluid Engineering, Cranfield, UK, pp. 91-101.).

Tests have shown that for a large number of heterogeneous slurries without excess fines and in the heterogeneous region of interest, the above may be simplified to

$$i_m = i_f + (S_m - 1)\left(\frac{U_u}{V_m}\right)^{1.7} \qquad (1)$$

as outlined by Carstens and Addie (Addie, G.R., 1982, Slurry pipeline friction using nomographs. Froc. District 2 Meeting, (Sept lles, Quebec), Canadian Inst. Mining and Metallurgy.). Where the U_u constant is shown in Figure 3 from Addie plotted for different D50 mean size slurries and the form of equation 1 is the expected inverted parabola shown in Figure 1.

The minimum head loss V_{sm} value in Fig. 1, calculated using the above for clean (no fines) crushed rock slurries for different constant (operating) concentrations in different diameter pipe sizes is shown in Table 2.

Table 2
Minimum Head Loss (Stable) Velocity (ft/sec)
(Horizontal Pipe, Solid's SG 2.65, Particle Shape Factor 0.26)
for Clean (No Fines) Crushed Rock Slurry

Pipe Size	Concentration	Particle Size (D50) Micron			
Inch	% by Vol.	100	500	1000	5000
4	10	4.0	8.2	9.3	11.4
	20	4.9	10.0	11.3	13.8
	30	5.5	11.2	12.6	15.5
8	10	5.1	10.3	11.7	14.4
	20	6.2	12.5	14.2	17.4
	30	6.9	14.0	15.9	19.4
15-1/4	10	6.3	12.8	14.5	17.7
	20	7.6	15.5	17.5	21.4
	30	8.6	17.3	19.6	23.9
17-1/4	10	6.6	13.3	15.1	18.4
	20	8.0	16.1	18.2	22.3
	30	8.9	18.0	20.4	24.9
19-1/4	10	6.8	13.8	15.6	19.1
	20	8.2	16.7	18.9	23.1
	30	9.2	18.7	21.1	25.8
24	10	7.3	14.8	16.8	20.5
	20	8.9	17.9	20.3	24.8
	30	9.9	20.0	22.7	27.7
30	10	7.9	15.9	18.0	22.0
	20	9.5	19.2	21.3	26.6
	30	10.7	21.5	24.3	29.7

Slurries vary considerably and while the above holds for most of slurries in the range of sizes noted, it does not apply to very large particles and coal where the particle shape (and solids SG) is different from that of conventional crushed rock.

Other methods of calculating the head loss characteristics of heterogeneous slurries exist. These give roughly comparable values or, at least, produce the same characteristics.

Regardless, most settling slurries have a horizontal pipe head loss characteristic of a U shape with a minimum head loss which can be called the minimum stable operating velocity.

Centrifugal Slurry Pump Performance

If a given pump is driven at a constant shaft speed (i.e. fixed N), a series of readings of Q, H and P can be obtained at various openings of throttling value located downstream of the pump. The head is plotted directly against discharge, as shown on Figure 4. This curve is known as the head-discharge characteristic, or the head-quantity (or head-capacity) relation, or simply the H-Q curve. The required power and the efficiency are also plotted against Q, as shown on the Figure 4, which illustrates representative pump characteristic curves.

With N constant the efficiency η varies only with the ratio HQ/T, where T is always greater than zero. Thus, η will be zero at the no-flow condition (Q=0) and again when the H-Q curve intercepts the discharge axis (here H=0). Between these extremes the efficiency curve displays a maximum, as shown on the figure. This maximum defines

Effect of Solids on Performance

The presence of solid particles in the flow tends to produce adverse effects on pump performance.

The effects on pump characteristics are shown schematically on Figure 6, which is a definition sketch for illustrating the reduction in head and efficiency of a centrifugal pump operating at constant rotary speed and handling a solid-water mixture. In this sketch, η_m represents the pump efficiency in slurry service and η_w is the clear-water equivalent. Likewise, P_m and P_w are the power requirements for slurry service and water service, respectively. The head H_m is developed in slurry service measured in height of slurry, while H_w represents the head developed in water service, in height of water. The head ratio H_r and efficiency ratio η_r are defined as H_m/H_w and η_m/η_w, respectively. The fractional reduction in head (the head reduction factor) is denoted by R_H and defined as $1-H_r$; for efficiency the fractional reduction (efficiency reduction factor) is $R\eta$, given by $1-\eta_r$.

Values of R_H and η_r vary from zero to 10% for most heterogeneous slurries, but can be higher as solids size and concentration get higher. Reasonably accurate values for R_H and η_r may be predicted from charts in Wasp and Wilson.

Stability Considerations

Figure 7 shows typical 'system characteristics' for a settling slurry at three delivered concentration, in two forms. In Fig. 7(a), the friction gradient is expressed as head of carrier liquid, i_m, while Fig. 7 (b) gives the same information in terms of head of

slurry, j_m. For simplicity, only the frictional contribution is considered here; i.e. the discussion refers to horizontal transport.

The total developed head measured in terms of delivered slurry density (Fig. 7(b)) decreases slightly with increasing concentration, due to the effect of solids on pump performance discussed in Wasp and Wilson. Therefore the pump discharge head, measured as the water column equivalent to the discharge pressure of the pump, increases with slurry concentration. This increase is in slightly less than direct proportion to S_{md}. For the case illustrated by Fig. 7, where the pump has been selected for operation close to the 'standard' ———————————————————————————

velocity at point A, the system can accommodate variations in solids concentration from zero up to the maximum shown: there will be some reduction in mean velocity as C_{vd} increases, because of the effect of the solids on the pump characteristic (Fig. 7(a), but the variation in steady-state operating conditions is slight.

However, the transient behavior is more interesting. Consider the case where the system has been operating steadily at concentration 2, and the slurry presented to the pump suddenly changes to the higher concentration 3. Referring to Fig. 7(a), the system characteristic is now as 2, but the pump is handling a higher-density material so that its discharge pressure increases to characteristic 3. Thus, the immediate effect is to shift the system operating conditions to point B, increasing both the mean slurry velocity and the power drawn by the pump. As the higher solids concentration propagates along the line, the system resistance moves up to characteristic 3, so that the velocity decreases and system operation moves back to point C. Conversely, if the system has been operating

steadily at point A and the slurry entering the pump is suddenly reduced to concentration 1, the mixture velocity is reduced as the system moves to point D. As before, the system resistance now moves gradually back to characteristic 1, and operation moves back to point E.

Figure 8 illustrates operation of the same system but with pumps selected to operate further back on the system characteristics, giving a velocity below the 'standard' value at concentration 2. The result of increasing solids concentration to characteristic 3 is now to be considered. As before, the effect on the pump occurs before the new concentration has propagated along the pipeline, so that the immediate effect is to shift operation from A' to B'. The system again responds more slowly, and the pipe velocity therefore decreases from the maximum at B'. However, in this case, steady operation at concentration 3 is not possible with fixed-speed pumps, because they cannot generate sufficient head. Thus, when the system reaches a characteristic corresponding to 3a, the velocity abruptly reduces back into the deposit region. In other words, the line becomes 'plugged'. Figure 8(a) shows that reducing the solids concentration, even to the point of pumping water alone, cannot clear the plug; higher pump speeds are needed, or alternatively slurry of fine particles may shift the deposit. If variable-speed pump or clay slurry is not available, the only recourse will be to open up the line at some intermediate point and pump the solids out.

Two general conclusions can be drawn from the foregoing discussion. Comparing the system and pump characteristics is essential, because it enables qualitative but very informative assessment of operating stability. For systems driven by centrifugal pumps,

operation at velocities below the 'standard' velocity is feasible only for relatively fine slurries (see below) or for systems where the solids concentration is not subject to wide variations.

Figure 8 also illustrates why the velocity at the limit of deposition is often unimportant for settling slurries; although operation led to a 'plugged line', the cause was poor matching (or control) of the pump and system characteristics, rather than operation too close to deposition. This also illustrates why field data often indicates (so called) deposit velocities much above the calculated values; they actually correspond to the limit of stable operation with centrifugal pumps, rather than the limit of operation without a stationary deposit. In practice, centrifugal pumps permit operation near the deposition point only for relatively fine particles.

Where the pipeline head includes a large static component such as in mill cyclone feed and other circuits, then the system characteristic is flatter and the above behavior may be more pronounced.

Similar (but different) effects are seen in Ref. 5 for the effect of particle size. Here, the solids effect on the pump plays a big part.

<u>Operation of Prior Art in the Field</u>

Operation in an unstable way as described results in plugging of a line or in the case of a system where the suction sump level is significant in relation to the total head, it may just result in large swings in flow through the pump as the pump stops pumping and then restarts as the sump level increases and lowers the system characteristic back down below that of the pump.

Cyclone feed service is a good example here. Often the dictates of the mill and the grinding process force operation at a flow that is unstable. Here, the pump often is forced to run with the sump emptying and filling with the flow surging wildly back and forth. It is possible that the average flow will satisfy the mill needs. The result on the pump, however, is excessive wear and tear due to the large variation of percent of BEP quantity flow operation.

As noted earlier, the operating point must always be where the pressure produced by the pump is equal to that of the system, the resistance of the system being a function of the SG of the mixture, the elevation (or static head) change, the friction in the pipeline and any cyclone pressure.

These (system values) can usually be measured or calculated using magnetic, venturi or Doppler flowmeters; with nuclear 'U' loop or other density meters and a variety of different pressure gauges noting that where the static head is large in relation to the friction a flow and SG measurement with calculated pipeline friction and elevation (from measured level differences) head may be used.

Here, it should be noted that the slurry is incompressible for all practical purposes and the flow is the same in the pump and the pipeline. The density size of solids, etc., on the other hand can vary along the pipeline. If, however, we average readings over the average time it takes for the slurry to go through the system, (normally in cyclone feed service about 10 seconds), then we can establish a good overall average of the pipeline resistance at a given time.

The balancing pressure (or unbalancing as the case may be) produced by the pump is directly related to the pump, its speed, the flow and the density or SG of fluid inside the pump at a particular time. The performance of the pump on clear water at a given speed and flow is usually known in terms of its tested water performance for the head produced and power consumed.

The pump-input power is normally available either as electrical motor driver watts or amps, possibly a measured torque or even pressures and/or rack position for a diesel engine driver.

Regardless of how it is collected the pump-input power can be calculated using one or more of the above methods using the readings noted and as necessary known or determinable motor, gearbox or other efficiencies. Here, it should be noted that in almost all cases that the power reading can be obtained over a short period of time (or instantaneously) as necessary.

Using the pump input power and the known pump characteristics.along with known calculated or measure solid effect corrections for the slurry effect or the performance in relation to its water performance, then an instantaneous pressure produced by the pump and SG within the pump can be determined.

SUMMARY OF THE INVENTION

This invention is therefore about a way of determining the instantaneous pressure produced by the pump (and the internal SG that goes along with that) and how that can be used in relation to the overall total pipeline resistance to control and/or adjust the pump performance to better operate the pump and/or reduce or eliminate the unsuitable unstable

operation described earlier, and all of the adverse cavitation, wear and other effects on the pump and pipeline that go along with that.

DETAILED DESCRIPTION

Specifically this invention is about using the measured pump input power, the known or measured speed, the previously known performance of the pump (either on slurry or with solids effect corrections relative to water) to determine the instantaneous pump driving pressure (and SG) and of using this to better control the pump so that it operates in equilibrium with the system and in a stable manner.

The system pressure used for comparison here would be one determined normally on a continuous average basis. This could be the calculated sum of the system static head, cyclone pressure and pipe friction using conventional flow and SG meter measurements or could even be from a system pressure sensor.

Stable operation would in principal aim to keep the instantaneous pump pressure in equilibrium with the continuous average system pressure, while at the same time, satisfying input flow and sump level constraints.

As noted before, we use for determination of the instantaneous pump pressure and SG the commonly accepted relation of

$$P = \frac{Q \bullet H_m \bullet SG}{3960 \bullet \eta p} \qquad (3)$$

where

P	=	pump input power in horsepower
Q	=	USgpm units of flow
H_m	=	pump head in ft of slurry mixture
SG	=	specific gravity of the mixture inside the pump.
ηp	=	pump efficiency

Noting that the term ηp depends mainly on the pump quantity Q at a given rotating speed N but also should be corrected or adjusted for the effect of solids size, SG, etc.

The ηp and H value depends partially on the SG which is known initially only in the combined term H x SG. Initial values of ηp and H used, however, can be found from the previously established water performance test values for the pump at the measured flow and rpm to determine an initial SG. Then final values of ηp and H can then be determined by using a solids effect correction and resubstitution of the SG value until the difference in the SG used in the correction is close to the value determined in the combined term.

In the first case therefore knowing the pump instantaneous input power, the rpm and the system flow and system SG we can, using the pump tested or estimated water performance, determine in the first case the pump efficiency without solids effect.

The term H_m x SG in this case (at this stage), represents an approximate value of the instantaneous pump pressure in units of pressure usually of feet of H20.

Now, however, using the known pump size, the approximate slurry size and the average system slurry SG to determine a solids effect value for H_R and η_p in the equations from Wilson.

$$HR = H_m/H_w \text{ and } \eta p = \eta_m/\eta_w$$

and again using the tested or estimated water performance curve a more precise instantaneous value of slurry SG may be calculated using equation 3.

If the values of HR and ηp are adjusted to reflect the new instantaneous SG and

the above repeated until the changes in SG are small, then a close estimate of the instantaneous pump pressure and internal concentration (SG) can be determined for use in the control of the pump.

In the above, the value for P is usually determined by the instantaneous reading of the driver input power. In the case of an electric driver, this could be from a wattmeter and a correction for the motor efficiency or it could be using the instantaneous amps. Using the commonly known relation

$$P = \frac{\sqrt{3}EI\cos\phi\eta_m}{.746}$$

where

E	=	volts
I	=	amps
$\cos\phi$	=	motor power factor usually 0.8 for a 3 phase motor and
η_m	=	motor and/or gearbox efficiency

The instantaneous specific gravity or SG is the unknown or determined value here which in turn, depending on the slurry, can be used with a correction (as described) to determine the pump pressure produced in feet of units of H20.

$$\underset{\text{(pump)}}{\text{Pressure}} = SG \,.\, H_m$$

In a control system, therefore the instantaneous pump pressure can be used to compare with the resisting pressure of the system usually determined using the measured overall elevation differences, a SG measurement taken over the time (approximately) the slurry takes to go through the system and a calculated value for the pipe friction component using

$H_{system(ft\ H20)}$ = elevation diff. X SG + Pipe Friction + any cyclone pressure As described earlier.

The difference between the value of Gap Pressure (pump) above and the H_{system} value (and also alternatively the pump and system SG values) represents the instantaneous destabilizing driving pressure.

This difference can then be used in a control circuit (with appropriate timing and averaging) or other method to correct the imbalance by the common methods known. Here, adjusting the speed of the pump using the commonly known affinity laws of

$$H_2 = \left(\frac{N_2}{N_1}\right)^2 H_1$$

where

H = pump head
N = pump speed
1 = initial
2 = final

would be a likely method but if possible a rapid change of incoming SG, sump level (special additions) or other could be used.

The invention provides a method of comparing the pump instantaneous internal pressure of SG with the system pressure can be used to control slurry pump operation in a slurry pipeline.

The instantaneous driving force or pressure that is controlled (and destabilized) by the incoming change in slurry SG solids size, etc., (in relation to the system) can be determined and that it then can be used in relation to the overall system head to reduce or

eliminate instability in operation.

The measured input power of a pump along with its known performance can be used to calculate an instantaneous pump pressure and internal density that when compared with an overall system resistance calculated from the elevations, flow, specific gravity and friction head component can be used to adjust the pump performance to minimize or eliminate unstable operation.

By the use of this technique or method operation in a so called unstable region more steady and even operation will be possible and that this will benefit mining and other customers whose processes and systems require this.

By the use of this technique or method, operation in an unstable region will be possible with the instabilities, the damage and increased wear to the pump that go along with this reduced or eliminated.

The effective instantaneous pressure produced by a slurry pump can be determined from the pump instantaneous input power, rpm, flow and other parameters.

The effective instantaneous mixture specific gravity inside a slurry pump can be determined from the pump instantaneous input power, rpm, flow and other parameters.

The effective internal pressure of an operating slurry pump can be used to control or stabilize operation of that pump or pumps in a pipeline system.

WHAT IS CLAIMED IS:

1. A method of controlling the operation of a slurry pump of the type including an electric motor, a centrifugal pump driven by said motor, said pump including an inlet for communication with a slurry, and an outlet for communication with a delivery conduit which develops a back pressure; the improvement therein of:

using the instantaneous driver power provided to said motor in accordance with:

$$P = \frac{Q \bullet H \bullet SG}{3960 \bullet \eta p}$$

where:

P	= pump input power in horsepower,
Q	= Usgpm units of slurry flow,
H	= head of pump across pump inlets in feet of slurry mixture,
SG	= specific gravity of the mixture inside the pump, and
ηp	= pump efficiency,

to determine the combined $H \bullet SG$ instantaneous pressure term produced by the pump for a given slurry pipeline system flow; and

varying the performance of the pump to keep the pressure term $H \bullet SG$ in stable equilibrium with the effective slurry pipeline system pressure;

where the value of P is determined by the short time instantaneous reading of the motor pump input power and calculated in accordance with:

$$P = \frac{\sqrt{3} EI \cos\phi \eta_m}{.746}$$

where:

E	= volts,
I	= amps,
$\cos\phi$	= motor power factor usually 0.8 for a three phase motor,
η_m	= motor and gear box efficiency.

2. The method of claim 1 and wherein the initial values of H and ηp in the expression

$$P = \frac{Q \bullet H \bullet SG}{3960 \bullet \eta p}$$

are obtained from the previously obtained water performance of the pump and later corrected for the effect of the known pump size, known solid size, known solids SG and calculated SG by resubstitution of the SG value until the SG difference between the value used for the correction and the value determined from

$$P = \frac{Q \bullet H \bullet SG}{3960 \bullet \eta p}$$

is less than .01.

3. The method of claim 1 and wherein the step of varying the performance of the pump comprises varying the particle size of the slurry.

4. The method of claim 1 and wherein the step of varying the performance of the pump comprises varying the level of the sump at the inlet of the pump.

5. The method of claim 1 and wherein the step of varying the performance of the pump comprises varying the speed of the pump.

6. A method of controlling the operation of a slurry pump of the type including a motor, a centrifugal pump driven by said motor, said pump including an inlet for communication with a slurry, and an outlet for communication with a delivery conduit which develops a back pressure; the improvement therein of:

using the instantaneous driver power provided by said motor in accordance with:

$$P = \frac{Q \bullet H \bullet SG}{3960 \bullet \eta p}$$

where:

P = pump input power in horsepower,

Q = Usgpm units of slurry flow,

H = head of pump across pump inlets in feet of slurry mixture,

SG = specific gravity of the mixture inside the pump, and

ηp = pump efficiency,

to determine the combined H•SG instantaneous pressure term produced by the pump for a given slurry pipeline system flow; and

varying the pump speed to keep the pressure term H•SG in stable equilibrium with the effective slurry pipeline system pressure.

7. The method of claim 6 and wherein the step of varying the performance of the pump comprises varying the particle size of the slurry.

8. The method of claim 6 and wherein the step of varying the performance of the pump comprises varying the level of the sump at the inlet of the pump.

9. The method of claim 6 and wherein the step of varying the performance of the pump comprises varying the speed of the pump.

Thomas/Utility Pat/11191-1010

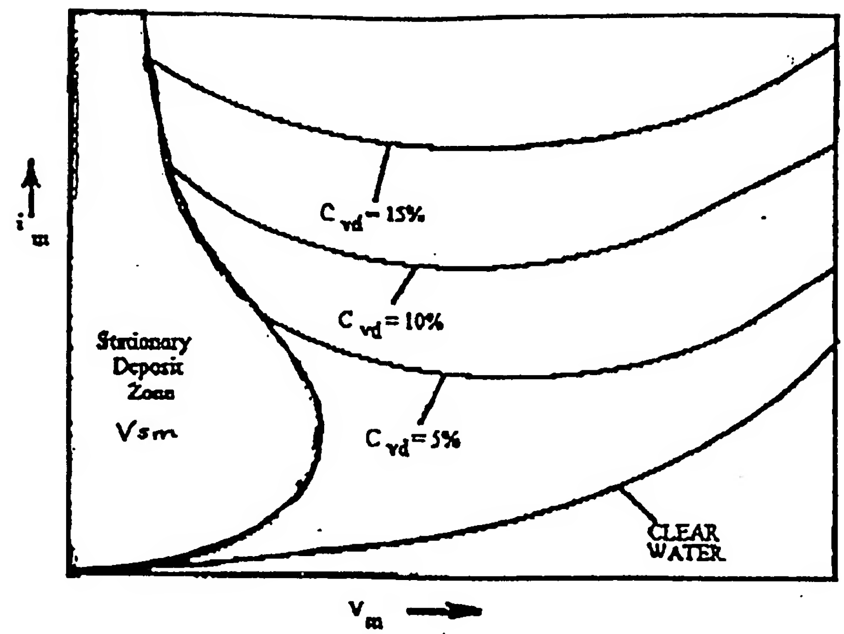


Figure 1

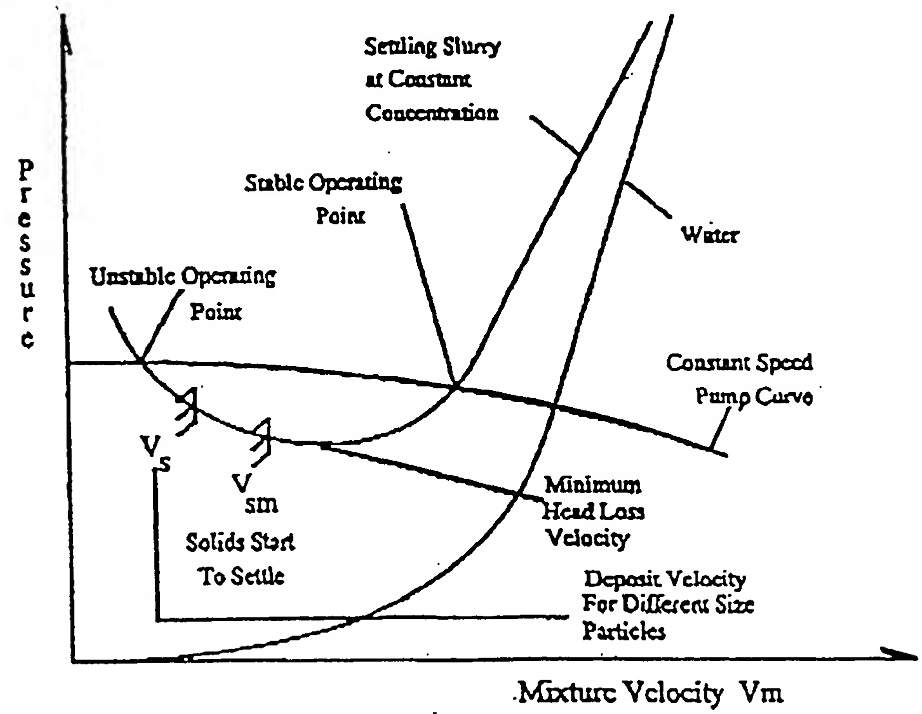


Figure 2

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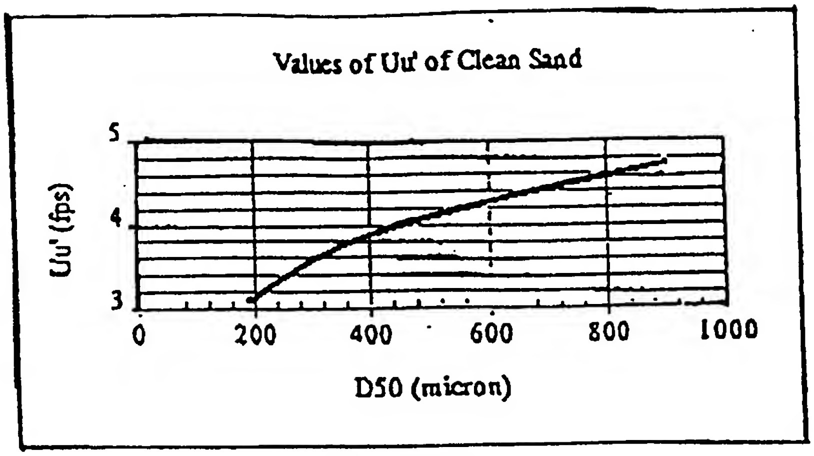
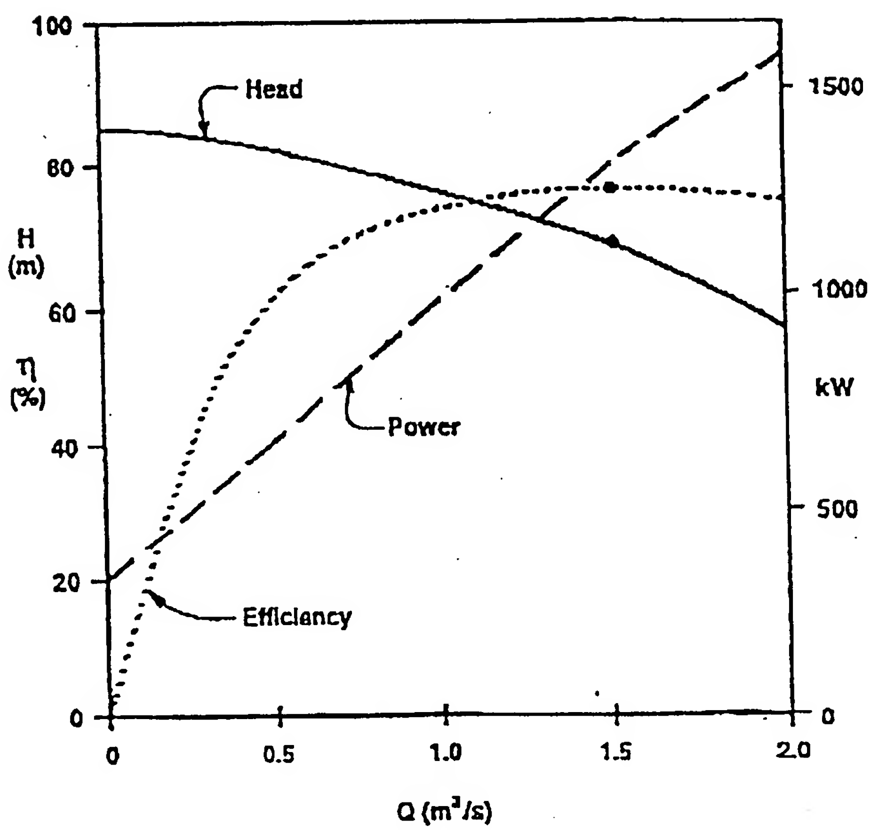


Figure 3.



Representative pump characteristic curves.

Figure 4.

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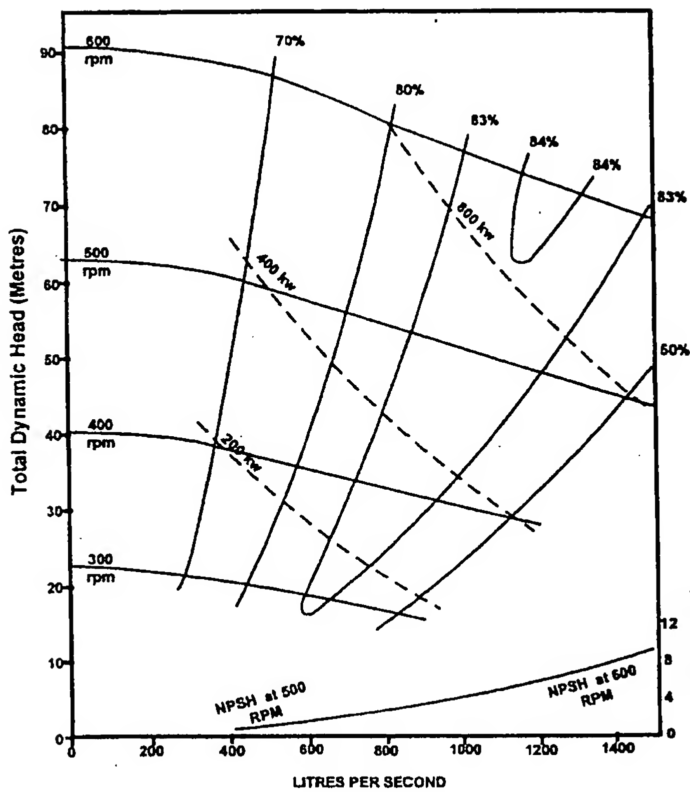

Fig. 5 Pump performance chart.

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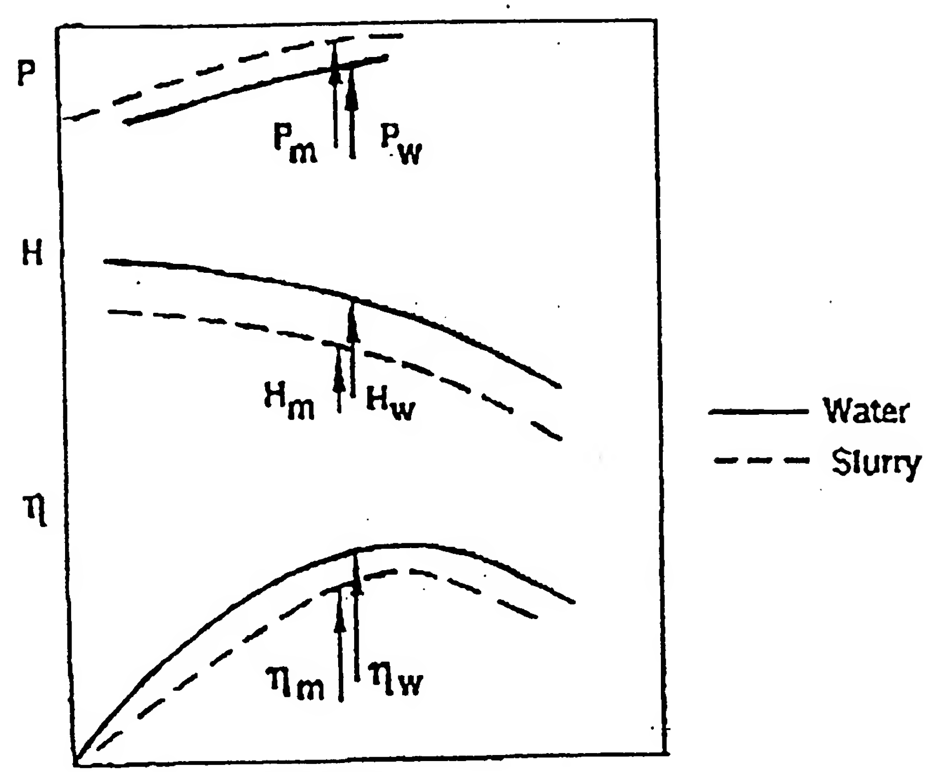

Effect of slurry on pump characteristics (schematic).

Figure 6.

Finlayson & Singlehurst

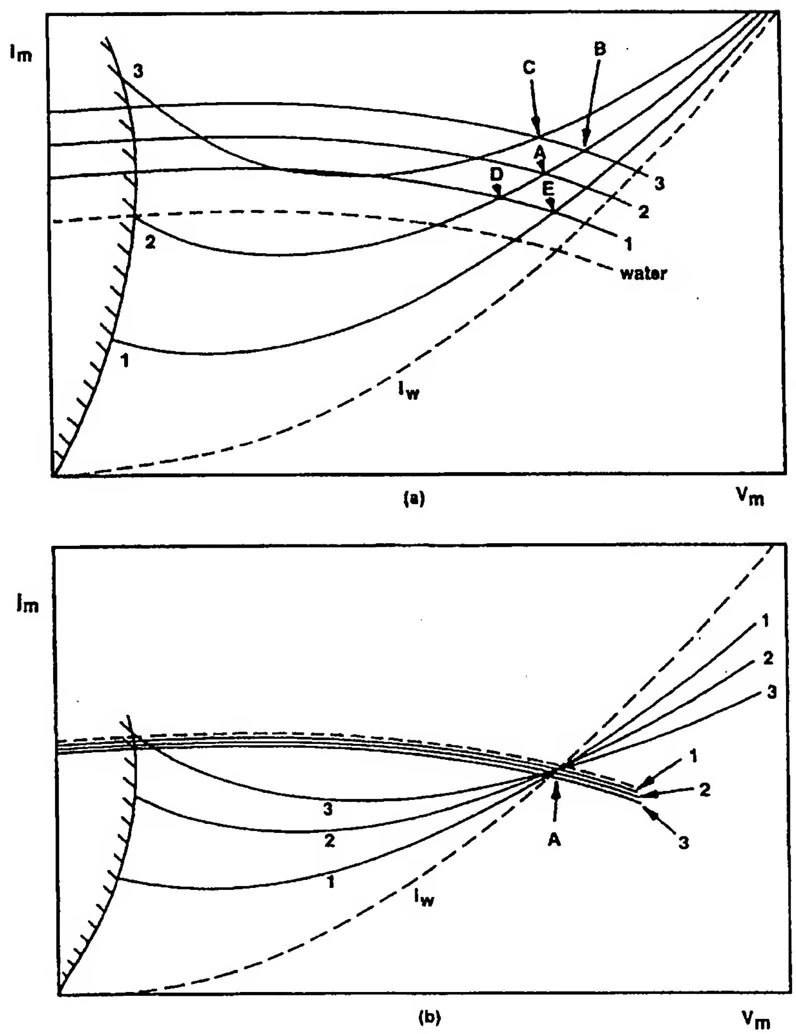

Fig. 7 System and pump characteristics for heterogeneous flow of a settling slurry at various delivered concentrations (schematic).
a) In terms of head of carried liquid.
b) In terms of head of slurry.

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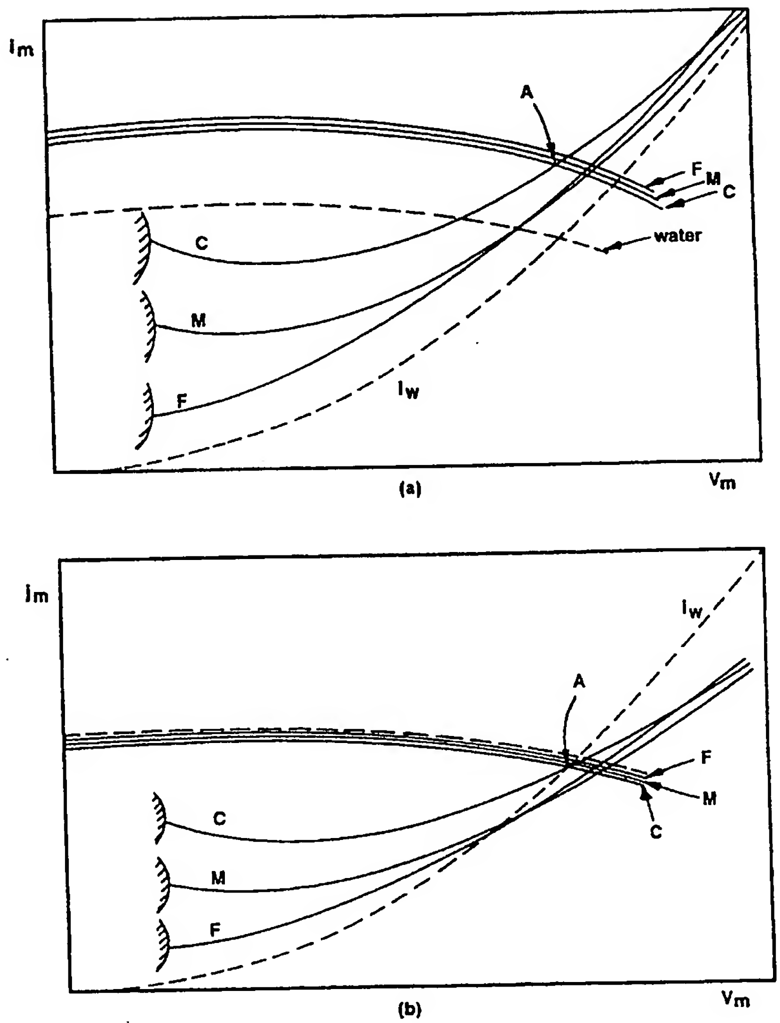

F - Fine; M - Medium; C - Coarse.

Fig. 8 System and pump characteristics for heterogeneous flow of slurries of various particle sizes.

a) in terms of head of carried liquid.
b) in terms of head of slurry.

Fetherstonhaugh & Co.

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